GRADUATING REFLECTIVE SCIENCE TEACHERS THROUGH PROBLEM BASED LEARNING INSTRUCTION

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Abstract. Researchers acknowledge the professional development of science teachers as the most critical component in reforming science education. Teachers' needs for professional development in science education are not always met by existing pre-service preparation programs. This paper argues that by incorporating problem-based learning strategies in pre-service science methods courses we can graduate more reflective practitioners, as it is the case in the medical profession.

Keywords: problem-based learning, pre-service science teacher education

Introduction

Many science educators see teachers' professional development as the most critical and complex variable in science education reform movement (Moore, 1997; Wheeler, 1998; Moreno, 1999). Furthermore, the National Research Council (NRC) standards 1996, p. 56,[1)] state "since the current reform effort requires a substantial change in how science is taught, an equally substantive change is needed in professional development practices". Moreover, the NRC standards recommend teachers should have opportunities to learn science content and inquiry- based teaching strategies in collegial environments that allow for sharing of knowledge, encourage them to connect their learning directly to the context of their own classrooms, and help them integrate technology and mathematics with science (Darling-Hammond & McLaughlin, 1995; Moreno, 1999). Additionally, teachers need opportunities to talk about students and student learning, about teaching, and about subject matter.

The goal of teacher education programs should not be to indoctrinate or train teachers to behave in prescribed ways, but to educate teachers to reason soundly about their teaching as well as to perform skillfully (Fenstermacher, 1986). Better prepared teachers are strikingly more effective in developing higher-order thinking skills and meeting the needs of diverse students through different learning approaches (Begle, 1979; Druva & Anderson, 1983). Conceptual teaching of problem solving and thinking skills, life relevancy, and life experiences are recommended by science educators (Rutherford & Ahlgren, 1990). Problem solving and thinking skills that revolve around life experience may be better taught through a student-centered classrooms that emphasizes process-oriented learning (Cachapuz & Paixao, 2002). Pre-service teachers must be presented with teaching strategies that challenge their thinking and encourage them to ask questions and where the focus of instruction is on meaningful conceptualization (Cachapuz & Paixao, 2002; Stronge, 2002). Vigorous modeling of student-centered, process-oriented classrooms where instructional time is maximized and integrated with technology must take place in classrooms where teachers actually learn science content (The Holmes Group, 1986; Stronge, 2002). Furthermore, according to the Holmes Group[2)], 1986, in order for education to change, undergraduate pre-service education must change. This article argues that incorporating problem-based learning (PBL) instruction in pre-service science teaching programs would help us to achieve some of these goals.

To support this argument, this paper first presents historical development of PBL, and then describes the characteristics of PBL. Next, it outlines research that supports the use of PBL and presents a rationale for implementing medical schools' PBL model in schools of education. Then the paper explains what PBL will do in pre-service science programs and concludes with an ideal vision for the future of pre-service science programs in the light of PBL.

Historical Development of PBL

The origin of problem-based learning, as Goodnough states[3)], "can be traced to the writings of Dewey (1944) who emphasized the connections amongst doing, thinking, and learning" (p. 3). According to Dewey, learning "should give students something to do....and the doing is of such a nature as to demand thinking or intentional connections." And PBL, Goodnough continues, provides the tools for fostering this type of thinking and active learning. Furthermore, Savery and Duffy (1995) state, PBL is an instructional approach that is grounded in many of the principles of the constructivist learning theory which sees learners as actively constructing knowledge through interactions with the environment and social negotiation.

PBL was originally developed at Canada's McMaster University's medical school in the 1970s by core of medical educators (Gallagher, 1997). Barrows (1988) acknowledges in his writings that new physicians were graduating with a lot of information but without the critical reasoning skills to use that information appropriately. In the medical model of PBL, learning is student –centered and takes place in small groups, teachers act as facilitators or guides, problems are the organizing themes for learning, problems are the means for the development of clinical problem-solving skills, and new understanding occurs through self-directed learning (Barrows, 1996).

Since the development of PBL, a number of other fields tried to adopt the medical school's PBL model. Boud and Felleti (1991) did a comprehensive overview of the applications of PBL in many different fields. Some studies tried to convert this unique approach to pre-college educational programs (Stepien & Gallagher, 1993; Stepien, Gallager & Workman, 1993). Various meta-analyses studies (Albanese & Mitchel, 1993; Vernon & Blake, 1993) have focused primarily on the outcomes of PBL instruction programs and a study by Goodnough[3)] has tried to focus on issues of process in planning for and using PBL as an instructional approach in pre-service science methods course. In their case study of a PBL unit, Peterson and Treagust (1998) found that PBL approach in primary science teacher education enabled participants to "develop their knowledge base for teaching and pedagogical reasoning ability, and to consider these two areas together when resolving a problem" (p. 234).

The Characteristics of PBL

Three characteristics set the parameters of PBL: a) initiating learning with a problem; b) exclusive use of ill-structured problems; c) and using the instructor as a facilitator (Gallagher, Stepien, Sher, & Workman, 1995). The following discussion will elaborate on these three characteristics.

Initiating learning with a problem

In a traditional classroom environment, prospective teachers encounter problems only after they have been presented with a body of information. However, the problem with this approach is that prospective teachers "often do not know why they are learning what they are learning" (Gallagher et al., 1995, p.137). PBL reverses this order of learning so that the processes of learning reflect the learning and problem solving that happens in professional practice (Gallagher et al., 1995). In PBL model learning begins after pre-service teachers are confronted with an ill-structured question. Teachers gather all the information for the unit with the purpose of resolving the ill-structured problem. Just as scientist would not do an experiment before identifying a challenging question, prospective teachers in a PBL classroom do not start learning until they encounter an ill-structured problem (Gallagher et al., 1995). For example, future teachers might be asked what they will do if they encounter a classroom where there are students with diverse learning needs, such as visual learners, musical learners, and group learners, and how they will teach the concept of equilibrium or photosynthesis to these diverse learners. So, in a PBL course future teachers can form groups of three or four and discuss how they might teach these concepts to the diverse groups of learners and actually teach it in a clinical school.

Exclusive use of ill-structured problems

Ill-structured problem is the key component of PBL (Gallagher et al., 1995; Jonassen, 2000; Weiss, 2003). Gallagher (1997) presented the key features of ill-structured problems and they are: more information than is initially available is needed to understand the situation or problem and decide what actions to take for the solution of the problem; no single formula exists for conducting an investigation to solve the problem; as new information is gathered, the problem changes; and prospective teachers can never be hundred percent sure they have made the 'right' decision, because an ill-structured problem does not have a single right answer.

Additionally, ill-structured problems are generative, that is, they immediately cause students to ask questions (Gallagher, 1997). Also, they are almost inherently interdisciplinary (Gallagher et al., 1995).

The problem should promote future teachers' knowledge and skills that have been clearly defined as intended course outcomes (Barrows, 1996). The general purpose of the problem should be to stimulate student activity and engagement (Weiss, 2003). A good problem should be based on a deep analysis of prospective teachers' current knowledge and must be challenging (Weiss, 2003). The ill-structured problem requires collaboration among teachers. Also, the problem should be authentic, that is, it should relate to prospective teachers' future plans and expected careers (Weiss, 2003). Professors in science education therefore need to design problems that require students to use content in ways indicative of emerging professionals (Weiss, 2003). Questions such as, you have a class of 25 students in six grade, one of them is blind, another two have dyslexia and three have communication problems how you are going to teach this class the concept of light? All these factors, in turn, might promote lifelong and self-directed learning among pre-service teachers.

Using the instructor as a facilitator

Instructors in PBL take on a new role; "instead of being experts or didactic instructors, they become meta-cognitive coaches" (Gallagher et al., 1995, p.138). They help future teachers understand what kind of questions to ask during problem definition, information location, analysis and synthesis, and also to sort through potential interpretations and solutions of the problem (Barrows, 1988). Most importantly, the instructor's role in PBL is to give voice to 'meta-cognitive questions'; that is to make students think about their own thinking when solving the problem (Gallagher, 1997). In the same line, the instructor in PBL classroom "express oneself in the language of the students, using the concepts they use and explaining things in ways easily grasped by students" (Schmidt & Moust, 1995, p.709). Professors help students to take on the role of problem-solver first by modeling and coaching expert inquiry, which include questions that promote critical thinking, and then by requiring that students take on the responsibility of using these skills on their own (Gallagher et al., 1995). Furthermore, instructors ask questions that assess students' learning needs so that they can form an 'educational diagnosis' about these needs (Barrows, 1988). Moreover, instructors' encourage open classroom discussions, monitor and maintain the cohesiveness of the groups, and make sure that all students are involved (Barrows, 1988). In this way, future teachers "can become truly self-directed and independent learners empowered to approach the complex problems they might face as professionals" (Gallagher et al., 1995, p.138). Additionally, in PBL, assessment is a part of 'procedural coaching'; authentic learning requires authentic assessment (Barrows, 1996). Instructors should use variety of assessment formats to determine what strategies are working, which students need more specific assistance, what content needs further review, and frequent assessment allows the instructor to respond to range of student needs and helps them to adapt their instruction to meet all students learning needs (Stronge, 2002).

, Finally, these characteristics of PBL approach answers the calls of science educators presented earlier in the introduction, and that is why PBL approach can help in restructuring science teacher preparation programs, so that they can graduate reflective practitioners, as it was the case with medical schools.

Research that Supports the Use of PBL

There are various research studies that support the integration of PBL instruction in number of fields. These studies support the notion that PBL improves prospective teachers' professional skills in various ways.

Studies by Coles (1985), Dods (1997), and Newble & Clarke (1986) revealed that PBL promotes more in-depth understanding of content than traditional methods. Lieux[4)] found that PBL increases students' interest in the content being studied, which in turn leads to stronger engagement in learning. MacKinnon (1999) revealed that students in PBL classes are more motivated than in traditional classes, because PBL creates a sense of community and allows students to take control of their own learning. Gallagher and Stepien (1996) found that PBL increases students' higher-order thinking skills. Gallagher, Stepien and Rosenthal (1992) in their study of interdisciplinary PBL course revealed that the course was effective in shaping students' problem-solving processes. Norman and Schmidt (1992) concluded that students in PBL classroom are more likely to be successful as self-directed learners, because they are able to transfer their problem-solving skills to the real world. Dean[5)] emphasized that students considered PBL to be effective in enhancing their confidence in judging alternatives for solving problems.

Although, the above mentioned studies are from various different fields, they could shed light on what might be gained if we implement PBL in the science teaching programs.

However, researchers also pointed some of the limitations to PBL. Hung, Bailey, and Jonassen (2003) stated PBL instruction limits the possibility of students being exposed to broader content and requires enormous amount of time to be implemented effectively, and outlined five tensions of PBL from empirical research that may be of concern to science instructors: "depth versus breadth of curriculum, higher-order thinking versus factual knowledge acquisition, long-term effects versus immediate learning outcomes, traditional roles of professors versus the role of PBL tutors, and students' initial discomfort versus their positive attitudes" (p. 13). These five tensions of PBL could also be its strengths, because teaching in ways that help prospective teachers gain more depth on specific topic and develop higher-order thinking skill in the long run might help them become reflective professionals.

Rationale for Implementing Medical Schools' PBL Model in Schools of Education

Medical schools implemented PBL in order to help their students learn the skills of expert reasoner and problem solver. This might have contributed to medical students' becoming reflective practitioners. Moreover, by implementing PBL medical schools wanted to achieve the following goals for their students: fostering clinical-reasoning skills, problem-solving skills, or both; enhancing acquisition, retention, and use of knowledge; improving students' self-directed learning skills; developing students' intrinsic interest in subject matter and, subsequently, their motivation to learn; developing students' capacity to see problems from multi-disciplinary viewpoints, integrating information from many different sources; facilitating the development of effective collaborative learning practices; emphasizing for students the importance of learning for understanding rather than learning for recall; and improving flexible thought and capacity to adapt to change." (Gallagher, 1997, p. 334).

Each of these objectives of medical schools' PBL model could be the desired goals for teacher preparation program, including science teacher preparation programs, if we want teachers to be seen and respected as professional like the physicians in the eyes of the public., Teachers, as expert decision-makers, will know how to diagnose, guide and re-diagnose every one of their students, just as one physician will diagnose and treat his patients (Merrill & Butts, 1969). Furthermore, problem solving is an important part of professional practice and professionals rely heavily on their problem-solving skills to handle the increasingly ill-structured nature of their work (Bereiter & Scardamalia, 1993; Schon, 1987). Students' mental health is as important as their physical health. Therefore, again taking in account the previously mentioned characteristics of PBL, integrating PBL instruction in pre-service teacher programs might help improve graduates' problem-solving skills, which in turn hopefully will make them reasoning professionals.

What will PBL do in Pre-service Science Programs?

PBL will addresses directly number of the major recommendations presented in the science education literature. First, PBL will address the calls for use of cooperative small learning groups. Science education researchers argue that the use cooperative groups promote the development of learning communities in science classes (Allen, Duch & Groh, 1996). Number of research studies revealed that student achievement is enhanced when students work together in a collaborative learning environment[6] (Bodner, 1992). Working in groups will also help graduates from pre-service science programs to develop essential characteristics of professionals necessary for success after graduation, such as verbal and written communication skills and team building skills (Czujko, 1994).

Second, by using PBL, future teachers will obtain knowledge in the context in which it will be used (Allen et al., 1996). They will investigate real science teaching problems that are relevant to them and which they will be able to use in their future practice. Researchers argue that students are more likely to retain what they learn and apply that knowledge appropriately when concepts are connected to applications (Coles, 1991; Dunkhase & Penick, 1990).

Third, PBL will help teachers to learn how to learn. The scientific and pedagogical knowledge bases are expanding rapidly, and prospective teachers will need to learn how to obtain relevant knowledge when they enter the practice (Allen et al., 1996). PBL promotes the ability to identify what information is necessary for a particular application, where and how to look for that information, how to organize it into a meaningful conceptual framework, and how to communicate that information in an organized manner (Allen et al., 1996).

Fourth, PBL will assist prospective teachers in learning the processes of inquiry and nature of science. In a PBL classroom teachers will learn how to do an investigation, just as one scientist will do it in real setting. By introducing an interesting, relevant problem up front in PBL, prospective teachers' attention and interest will be captured and allow them to experience for themselves the real process of doing science. They will proceed from the known to the unknown and in doing so they can sense the origins of a scientist's way of thinking (Allen et al., 1996).

Fifth, in PBL classrooms, future teachers will learn in first hand what it means to teach for conceptual change. Because once presented with a problem up front they will have some opinions about how to solve the problem from their prior experiences, and then by investigating the problem they will see how their thinking is changing when presented with new information.

Sixth, in PBL classrooms, teachers will learn problem-solving skills that are needed for a good action researcher or reflective practitioner. In PBL instruction prospective teachers will learn how to solve an ill-structured problem, just as the problems that may arise in their real classrooms in the practice.

Finally, by using PBL, teachers will learn how to make connections among different disciplines, because the use of problems to introduce concepts provides a natural mechanism to highlight the interconnections between different fields (Allen et al., 1996). They will learn how to connect their content knowledge with their pedagogical knowledge so that they can answer the different needs of different students.

The Future of Pre-service Science Programs in the Light of PBL

In the future, we can envision one ideal scenario for a pre-service science teaching program. In this program students will have the opportunity to observe expert professional teachers in a clinical K-12 school. Moreover, they will have the chance to teach in this school. In their methods classes, prospective teachers will solve ill-structured problems in their cooperative small groups of four or five. The classes will be monitored by instructors who underwent tutor development programs that stress how to realize active construction and meta-cognition (Allen et al., 1996). In this program prospective teachers will learn the skills of "expert diagnostic decision-maker" (Merrill & Butts, 1969, p. 35). As expert decision-makers, they will know how to diagnose, guide and re-diagnose every one of their future students, just as one physician will diagnose and treat his patients (Merrill & Butts, 1969). Future teachers, through careful and perceptive observations or listening, will know how to "identify which student is ready for what information and which level of this information may be best suited to the individual student" (Merrill & Butts, 1969, p. 36). Furthermore, making information accessible for every student will become a highly significant task for these teachers (Merrill & Butts, 1969). Prospective teachers will spent increasingly great time and effort in "helping their students establish and understand their goals and objectives and especially in helping students recognize the effect that various courses of action have in reaching these goals" (Merrill & Butts, 1969, p. 37). These teachers will find themselves working increasingly with other teachers in team-teaching, where solving each student's problems will demand multi or inter disciplinary approaches (Merrill & Butts, 1969). The "maintenance of professional competence will and should become a built-in part" in every teacher (Merrill & Butts, 1969, p. 40). As you may have noticed some of the roles future teachers will have are pulled from the Merrill and Butts' article written 39 years ago. In all of these 39 years we, as science educators, were not able to graduate enough science teachers who mach these descriptions, we were not able to reform most of our programs. Integrating PBL in our programs might be helpful in achieving most of these goals.

However, designing a new curriculum, developing new teaching tools, training science faculty to develop new teaching skills, and nurturing students through a fundamental change in learning, in short changing the whole system, is very expensive and time-consuming process (Barrows, 1996). Restructuring the pre-service science education programs and the educational system in general will require major shift in the mentality of policy makers and the lay public. It will require public that sees the development of their children's mental health as important as the development of their physical health. So that they can pressure the policy makers for equal founds in the nation's health and educational systems, equal founds for nations medical and educational schools. Thus, they can have equally professional physicians and teachers.

Notes

[1] *National Science Education Standards.* Washington: National Academy Press, 1996 http://www.nap.edu/readingroom/books/nses/

[2] Report of the Holmes Group, 1986: *Tomorrow's Teachers* http://www.holmespartnership.org/Tomorrows_Teachers.pdf

[3] Goodnough, K. Issues in modified problem-based learning: a study in pre-service teacher education. Paper presented at the American Educational Research Association (AERA) Conference, April, 21–25, 2003, Chicago.

[4] Lieux, E. M. (1996). A comparative study of learning in lecture vs. problem-based format http://www.udel.edu/pbl/cte/spr96-nutr.html

[5] Dean, C. D. Problem-based learning in teacher education. Paper presented at the American Educational Research Association (AERA) Conference, April, 19–23, 1999, Montreal.

[6] Johnson, D.W., Johnson, R.T. & Smith, K.A Cooperative learning: Increasing college faculty instructional productivity. Higher education report No. 4, George Washington University, 1991.

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